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SIGNATURE VERIFICATION FOR ACCESS CONTROL

by

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Access control to sensitive information is a vital concern for Department of Defense agencies. Current methods employed to control access are vulnerable to unauthorized users and frequently inadequate. The use of biometric access control devices, such as signature verification systems, may represent a solution to the access control problem. This thesis looked at two dynamic signature verification systems and compared their performance in general as well as under the different operating conditions of lined and unlined paper and morning and afternoon use. The two signature verification systems were the CIC system and the Sign/On system. Additionally, the thesis compared the CIC system under both sets of operating conditions using an inking stylus pen and a non-inking stylus pen. The experimental results indicated there was no significant difference between the CIC system using an inking stylus pen and the Sign/On system and that both systems had Type I error rates of less than 3% and Type II error rates of less than 1%. The results also indicated that the operating conditions test did not favor either system.

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Signature Veri cation for Access Control

by

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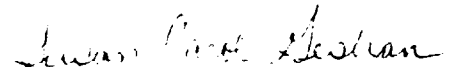
Author: 
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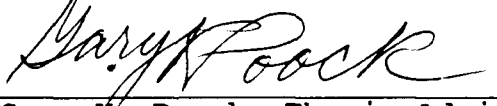
Approved by: 
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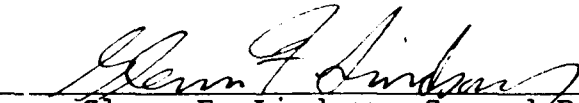
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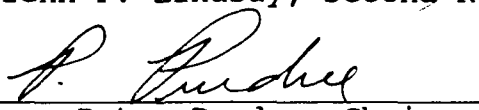
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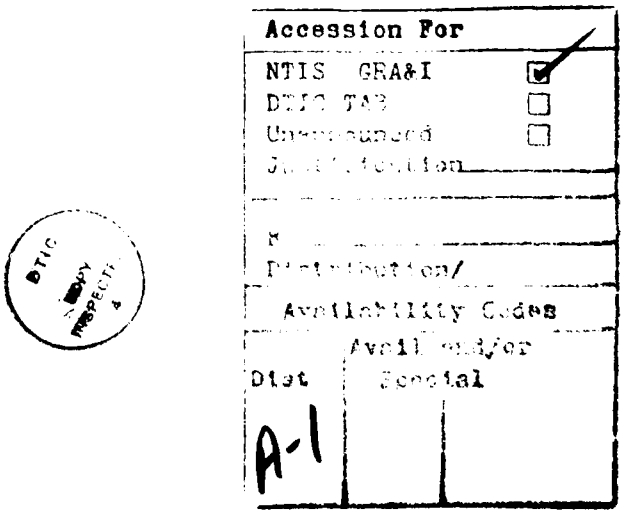
ABSTRACT

Access control to sensitive information is a vital concern for Department of Defense agencies. Current methods employed to control access are vulnerable to unauthorized users and frequently inadequate. The use of biometric access control devices, such as signature verification systems, may represent a solution to the access control problem. This thesis looked at two dynamic signature verification systems and compared their performance in general as well as under the different operating conditions of lined and unlined paper and morning and afternoon use. The two signature verification systems were the CIC system and the Sign/On system. Additionally, the thesis compared the CIC system under both sets of operating conditions using an inking stylus pen and a non-inking stylus pen. The experimental results indicated there was no significant difference between the CIC system using an inking stylus pen and the Sign/On system and that both systems had Type I error rates of less than 3% and Type II error rates of less than 1%. The results also indicated that the operating conditions test did not favor either system.



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I. INTRODUCTION

Access control to sensitive information is a vital concern for Department of Defense agencies. Because the cost of unauthorized access is often intolerable, the techniques used to control both physical access and computer access must be closely examined. In the interest of national security as well as personal privacy protection, adequate safeguards against unauthorized access must be guaranteed.

Access control is the security function whereby a user is identified and screened to discriminate authorized from unauthorized use (MIL-HNBK-1031/1, 1987, p. 114). There are two different types of personal identification and screening involved in access control (FIPS Pub 83, 1980, p. 9). The first of these is the actual establishment of identity. In this case it is the controlling system which is responsible for the identification of the person wishing access. The other alternative is to simply verify a claimed identity. A potential user would enter a claimed identity and then perform other system related tasks to verify the claim. Access would be granted or denied based upon the verification of identity rather than on the establishment of identity. Typically it is much faster and easier to verify an identity rather than establish an identity.

There are three basic methods used to verify a person's identity for access control (FIPS Pub 48, 1977, p. 7). These methods are:

1. Something a person knows.
2. Something a person possesses.
3. Something about a person.

The first method relies on such things as passwords, lock combinations, or other pieces of personal information to verify identity. The most common is the password. There are problems with this method in that the authorized user may forget the known information and be denied access or an unauthorized user may obtain the known information and be granted access. In either situation, access control was not effective.

The second verification method relies on such things as keys, badges, or passes. The degree of security provided by this method is limited, however, because possessions can be lost, stolen or duplicated. Additionally, accounting for each key or badge can be an administrative burden in the ever changing environment usually found in the Department of Defense.

Because of the inherent vulnerabilities in the other two methods, physiological attributes are being considered as possible bases for personal identification. Using physiological attributes for personal identification is one area in the field of study called biometrics. Some of the

physical attributes currently considered for access control are voice, retinal blood vessel patterns, signature dynamics, typing dynamics, three dimensional hand geometry, and fingerprints. The critical problem with biometric devices used for identity verification is the difficulty in performing precise, repeatable measurements on the human body (FIPS Pub 48, 1977, p. 10). This is especially true for the class of biometric devices which require a dynamic measure like speech or handwriting rather than a relatively static measure like a fingerprint. Another concern with biometric devices is the amount of interpersonal variation versus intrapersonal variation (FIPS Pub 83, 1980, p. 9). Interpersonal variations are those exhibited among different individuals whereas intrapersonal variations are those exhibited from the same individual from one measurement to the next. Introducing intrapersonal variations requires a much more sophisticated biometric device in order to verify identity.

Signature verification machines are one type of biometric device being considered for access control. Handwriting generally presents unique characteristics from one individual to the next. The signature, however, is even more unique and personally stylized because of a lifetime of practice. Often the signature is similar to a conditioned reflex and is written with little attention paid to each individual letter (FIPS Pub 48, 1977, p. 11). The end result of this

combination of features produces a highly individualized biometric measure which is very difficult to duplicate.

There are two basic methods used in signature verification systems (FIPS Pub 83, 1980, p. 33). One of these involves the comparison of a static signature. An example is a scanning device which measures only the written form of the signature. This method is extremely vulnerable to deceit. Another method compares a dynamic signature with a reference signature. In other words, the potential user submits a "live" sample signature which is compared to a reference signature. What this system measures has nothing to do with the signature's appearance, but with the forces generated by the user with the stylus or writing instrument (Bakke, 1986, p. 113) This method takes full advantage of how the signature is created. It is much more difficult to duplicate the dynamic motions used to create a signature than it is to duplicate the finished product.

There are many ways to obtain the signals which represent a dynamic signature. The quantities measurable during the writing process are positions, forces, and accelerations. Instrumentation designed to measure these quantities may involve the writing instrument (stylus) or writing surface (platen) or a combination of the two (FIPS Pub 83, 1980, p. 33). The vector of these "live" measurements is compared to the reference signature vector to verify identity. In theory, other written words may be used instead of the signature to

verify identity, however, signatures are preferable because of the level of conditioned response involved.

There are two dynamic signature verification systems in the Man-Machine Systems Design Laboratory at the Naval Postgraduate School in Monterey, California. One of them is produced by the Communication Intelligence Corporation and is called On-line Dynamic Signature Verification. This system consists of the stylus, the platen, and the software algorithms. Currently the system is connected to a personal computer for operation. The other system is produced by Capital Security Systems Incorporated and is called Sign/On. This system consists of the stylus, the platen, and a controlling unit with the software algorithm. The Sign/On is connected to a monitor for use. The purpose of this thesis is to design an experiment to evaluate and compare these two systems, analyze the statistical results, and report the findings.

II. THE EXPERIMENT

This experiment compared the effectiveness of two signature verification systems under different operating conditions. One of the systems was produced by the Communication Intelligence Corporation (CIC) and was called On-line Dynamic Signature Verification. The other signature verification system was produced by Capital Security Systems Incorporated and was called Sign/On.

The different operating conditions being compared were lined paper versus unlined paper, morning versus afternoon use, and an inking stylus versus a non-inking stylus pen. Only the CIC system was capable of operating with a non-inking stylus and therefore, the inking stylus pen versus the non-inking stylus pen condition was compared for that system alone. The comparison of these two systems under the different operating conditions may suggest preferred operating conditions for better performance and may indicate a more effective system.

A. THE EQUIPMENT

Both the Communication Intelligence Corporation and Capital Security Systems Incorporated were contacted to request specific information concerning the measurements

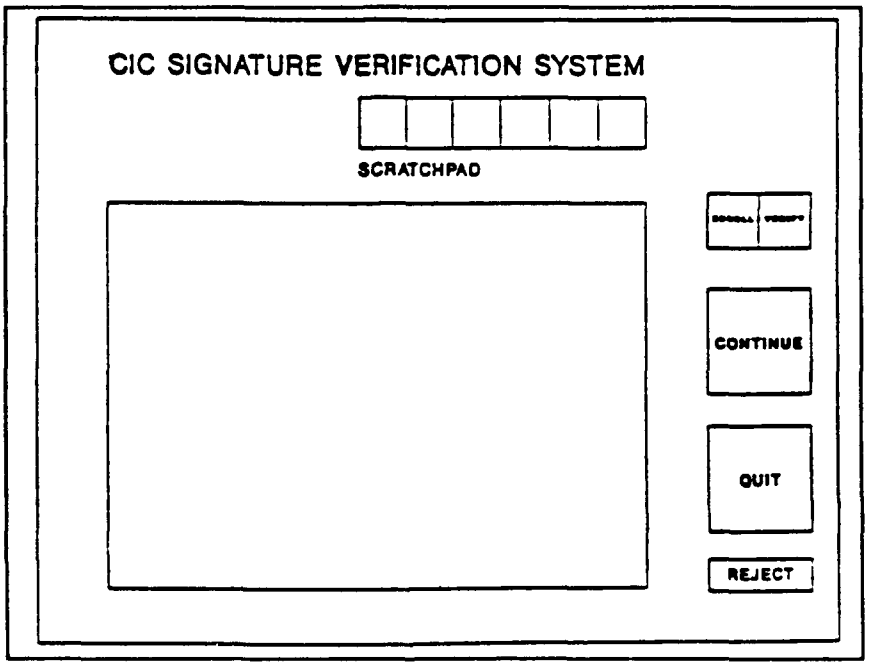
recorded for verification. Neither company chose to respond to the requests. Operating procedures for both systems are described below. However, generic information provided by the companies indicated each system works on the speed of acceleration and deceleration of the stylus movements and not on the pressure applied to the stylus.

1. The CIC System

When first approaching the CIC system the user is prompted by the monitor screen to select a mode of operation from the main menu. The choices are either enroll or verify. The user touches the stylus to the enroll or verify box (Figure 1) depending on the user's wishes. The monitor screen then prompts the user to enter his personal identification number (PIN) in the scratchpad. The user must print each of the alphanumeric characters in a separate box in the scratchpad. The monitor screen echoes the input from the scratchpad. The system must correctly identify the characters in order to retrieve the correct file. If a character recognized by the system is incorrect, the user simply writes the character over in the same box until it is recognized correctly. Once the PIN is correctly recognized, the monitor screen prompts the user to touch the continue box on the writing surface with the stylus pen for faster response. The system now retrieves the proper file and signature verification can begin.

The user is now prompted by the monitor screen to submit a signature. As before the user is asked to touch the continue box for faster response. After completion of the

Figure 1. CIC SYSTEM WRITING SURFACE



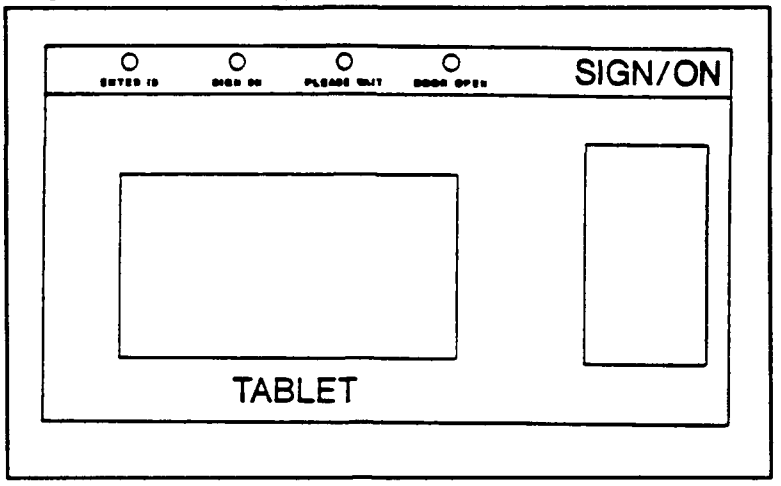
signature, the system compares the submitted signature to the reference signature for verification. Depending upon the comparison, the system may either use the monitor screen to prompt the user for up to two more signatures or make a verification decision. The system will prompt the user for another signature if the comparison of the signatures is "close" but not exact. However, after a total of three submitted signatures a verification decision must be made. If

the comparison is vastly different or exact, the verification decision can be made immediately. The results of the decision will be displayed on the monitor screen. The monitor screen will show the user that the system accepted the claimed identity or that the system recognized a forgery. At this time the user touches the quit box with the stylus to return to the main menu.

2. The Sign/On System

When first approaching the Sign/On system, the monitor screen and an illuminated light above ENTER ID on the writing surface prompt the user for a PIN (Figure 2). The user types the PIN on the monitor's keyboard. The writing surface has a series of red lights to prompt the user from this point until completion of the access attempt. After the PIN has been entered, the light above SIGN ON on the writing surface is illuminated. The user then submits a signature on the tablet. Based on a single signature the verification decision is made. If the system verified the claimed identity, the DOOR OPEN light illuminates. If the system rejects the claimed identity, all the lights above the writing surface flash. Additionally, the monitor screen duplicates the lighted verification decision. The system is then ready to prompt the next user for a PIN.

Figure 2. SIGN/ON SYSTEM WRITING SURFACE



B. PERFORMANCE MEASURES

The purpose of the experiment was to compare the performance of these two signature verification systems under different operating conditions. In order to accurately measure performance, two types of errors could be identified (Holmes, 1990, p. 2). They were:

1. Type I Errors: Falsely rejecting an authorized user.
2. Type II Errors: Falsely accepting an unauthorized user.

The perfect biometric device can positively distinguish interpersonal variances from intrapersonal variances and thus eliminate both Type I and Type II errors. In other words if

the biometric device can accurately identify intrapersonal variances, the result is a decline in the number of Type I errors. Similarly, if the device can correctly recognize interpersonal variations, Type II errors decrease. However, if the system is not perfect, it must adequately deal with both types of errors.

C. SUBJECTS

In all, 24 subjects were used in the experiment. They were all military officers at the Naval Postgraduate School (NPS) in Monterey, California. All were pursuing graduate degrees at the time of the testing. There were 5 females and 19 males ranging in age from 27 to 44 participating. None were familiar with signature verification equipment prior to testing and no incentives were given for participation. The two systems were set up in the Man-Machine Systems Design Laboratory at NPS and were available to the subjects from 0800 to 1700 each weekday. Testing was unsupervised to create a more realistic environment and data sheets recording the success or failure of each access attempt were collected each week of testing. The subject sample was considered representative of the population of military members requiring access to controlled areas and information.

D. ENROLLMENT

The first part of the experiment was the enrollment process. This process was the procedure by which the signature verification system converts a subject's signature into a reference template. A reference template is a sample of the subject's signature stored in memory to which an actual signature is compared when access is attempted. If, based on this comparison, the system verifies the subject's identity, access will be granted. Otherwise, the subject will be denied access.

Each subject was guided through the enrollment procedure by the experimenter. For the CIC system each subject was assigned a three letter PIN. The first action required by each subject was to select the enroll mode. This was done by touching the stylus pen to the enroll box on the system writing surface (Figure 1). Next the subject was prompted to enter his PIN in the system scratchpad. The subject was then prompted to write six signatures. After each signature the subject was given the choice to submit or reject the signature. Six submitted signatures were required for enrollment. The monitor then prompts the subject for one more signature to verify enrollment. At this time the signature template was created and stored in memory. To test the accuracy of the enrollment procedure and to familiarize the subject with the system, each subject was required to gain access three consecutive times. If any of these three

attempts were unsuccessful, the subject repeated the enrollment procedure from start to finish until three successful attempts to gain access were recorded.

The enrollment procedure for the Sign/On system was also guided by the experimenter. Each subject must again create a reference template. To create the template on the Sign/On system each subject first entered an assigned three digit PIN on the monitor keypad. The system illuminates the light above SIGN ON on the writing surface (Figure 2) to prompt the subject to submit two signatures. Thus the template was created and stored in the system's memory. Again each subject was required to gain access three consecutive times to become familiar with the system and to test the accuracy of the enrollment procedure.

Both systems used lined paper and inking stylus pens for enrollment. Half the subjects were enrolled in a morning session and the other half in an afternoon session. An enrollment procedure similar to the one described above might be appropriate for new users in an operational environment.

E. TESTING PROCEDURES

The experiment ran for a period of 10 weeks following the enrollment process. It was conducted in 4 phases. Phase 1 consisted of access attempts on both systems testing the effects of lined and unlined paper and morning and afternoon use. The CIC system allows the subject to write his signature

up to three times before access is granted or denied. However, if the signature is vastly different from the template on either of the first two signatures, access is immediately denied. In other words because the first signature is vastly different from the template stored in the CIC system's memory, three signatures are not permitted and access is immediately denied. With the Sign/On system the user is allowed only one signature after which a verification decision is made. In order to compare the systems for this experiment, however, the Sign/On system was adjusted so that the subject could attempt access with up to three signatures. A success on either system was defined to be access granted on any of three signatures.

The subjects were asked to attempt access four times per day on each system both in the morning and in the afternoon for three weeks. In total 16 signatures were collected from each subject each day. The systems were alternated between lined and unlined paper on a daily basis. The morning test period ran from 0800 to 1200 and the afternoon period ran from 1201 to 1700. The systems were available for four days per week to facilitate both paper conditions (lined and unlined paper). Subjects were asked to alternate their first access attempt each day between the two systems to eliminate any possible effects due to ordering.

Phase 2 of the experiment concerned falsely accepting unauthorized users, or Type II errors. This is also called

impostor testing. A list of subject identification codes for both systems as well as a sample signature was posted. Each subject was asked to attempt access using every other subject's signature. The impostor, or subject using another's identification code, attempted access on lined paper in the morning and afternoon and on unlined paper in the morning and afternoon. Each impostor attempted access in every other account one time for both time conditions and both paper conditions. Access was granted or denied on both systems based on up to three signatures per impostor depending on the comparison between the submitted signature and the reference template. Because of the difficulty in imitating another's signature, it was assumed the differences between the two systems in the number of signatures allowed before access was granted or denied would not matter. More specifically, the impostor signature and the reference template were assumed to be so different that the CIC system would make a verification decision on the first attempt. In total 24 impostor signatures per subject for each condition were collected.

Phase 3 was a replication of Phase 1 but only using the CIC system with the non-inking stylus pen. All subjects were re-enrolled in the CIC system as before. Lined paper was used for the re-enrollment with half the subjects re-enrolled in a morning session and the other half in an afternoon session. The experiment proceeded as described in Phase 1 with the CIC system and the non-inking stylus.

Phase 4 of the experiment was identical to Phase 2 using the non-inking stylus pen on the CIC system alone.

The data collected from all four phases of the experiment was analyzed to compare performance of the two signature verification systems. The Sign Test was used to compare the systems and a confidence interval was used to estimate the proportion of successful access attempts for both systems.

III. RESULTS AND DISCUSSION

After analyzing the data collected from the experiment, the Sign Test was determined appropriate to compare (1) the CIC and the Sign/On signature verification systems, (2) the CIC signature verification system with an inking and a non-inking stylus, (3) the CIC and the Sign/On systems for impostor testing, and (4) the CIC system with an inking stylus and a non-inking stylus for impostor testing. Two separate series of tests were completed for each of the four situations above. The first series consisted of 4 sets of four tests each and compared each system under the different operating conditions (lined and unlined paper; morning and afternoon use). The second series consisted of 4 tests that combined all four operating conditions and re-compared the systems. In all twenty different Sign Tests were completed. Additionally, three confidence intervals were calculated to estimate the proportion of successful access attempts for the CIC system with an inking stylus, the Sign/On system, and the CIC system with a non-inking stylus. Three more confidence intervals were calculated to estimate the proportion of successful access attempts during impostor testing for the CIC system with an inking stylus, the Sign/On system, and the CIC system with a non-inking stylus.

A. DATA COLLECTED

Due to unforeseen scheduling conflicts, seven subjects were unable to attempt access the requested total of 24 times for each operating condition. These seven subjects did, however, attempt access a total of 20 times for each operating condition. Because the data used to compute the statistics were proportions, the difference due to sample size between a proportion of 24 samples and one of 20 samples was considered negligible. Additionally, only 18 subjects participated in the phases of the experiment using the CIC system with the non-inking stylus. The smaller sample size was used in the comparison of the CIC system with an inking and a non-inking stylus.

B. SIGN TEST

The Sign Test is used in testing to determine if one random variable in a pair (X,Y) tends to be larger than the other random variable in the pair (Conover, 1980, p. 122). For this experiment, the random variable pairs were proportions of successful access attempts. The basis for pairing the observations was the common subject for each proportion. The proportions within the pair were not independent, however, each bivariate random pair was independent of the others. In addition, the pairs were consistent for each separate test.

1. The CIC System vs. The Sign/On System

For the four Sign Tests comparing the different operating conditions for the CIC system and the Sign/On system, the X's were defined to be the proportion of successful access attempts on the CIC system and the Y's were defined to be the proportion of successful access attempts on the Sign/On system. The test and the results from the first Sign Test comparing the two systems on lined paper in the morning are summarized in Table 1. The test clearly demonstrated that the combined operating conditions of lined paper and morning use did not significantly favor one system over the other. The significance level was 0.01.

The remainder of the Sign Tests and their results are in Tables 2 - 15 in the Appendix. Table 2 summarized the test and the results from the second Sign Test for the comparison of the CIC system and the Sign/On system under lined paper in the afternoon. Again the combination of operating conditions was consistent among the systems and did not indicate any difference between the two systems with a significance level of 0.01.

The results from third Sign Test are similarly summarized in Table 3. No significant differences between the performances of the CIC system and the Sign/On system were indicated by combining the operating conditions of unlined paper and morning use. The significance level was 0.01.

Table 1. SIGN TEST FOR THE CIC SYSTEM vs. THE SIGN/ON SYSTEM ON LINED PAPER IN THE MORNING

SUBJECT*	CIC	SIGN/ON	DIFFERENCE
1	1.000	0.950	+
2	1.000	0.917	+
3	1.000	0.875	+
4	1.000	0.900	+
5	0.917	0.958	-
6	1.000	0.917	+
7	1.000	0.958	+
8	0.958	1.000	-
9	0.875	0.958	-

The hypotheses are:

Ho: The CIC system and the Sign/On system have the same proportion of successful access attempts on lined paper in the morning

Ha: The CIC system and the Sign/On system do not have the same proportion of successful access attempts on lined paper in the morning

$\alpha = 0.01$

The observed number of minus signs is 3 out of a possible 9. From any Binomial Distribution Table, the corresponding probability level is 0.2539.

Because the probability level is greater than α, one **CANNOT REJECT THAT THE PROPORTION OF SUCCESSFUL ACCESS ATTEMPTS FOR BOTH SYSTEMS ARE THE SAME ON LINED PAPER IN THE MORNING AT A SIGNIFICANCE LEVEL OF 0.01.**

* only subjects with differences not equal to 0 were considered

The final Sign Test comparing the CIC system and the Sign/On system under the different operating conditions compared the systems under unlined paper with afternoon use. The test and results are summarized in Table 4. There was no significant difference between the two systems at a significance level of 0.01 on unlined paper in the afternoon.

In summary, neither of the operating conditions of paper nor time significantly favored either the CIC system or the Sign/On system. It should be noted, however, that because the same subjects were used in all the Sign Tests, the tests and their respective results are not independent.

2. The CIC System with Inking Stylus vs. The CIC System with Non-Inking Stylus

A second set of four Sign Tests was performed to compare the different operating conditions for the CIC system with an inking stylus and the CIC system with a non-inking stylus. In these four test the X's were defined to be the proportion of successful access attempts using an inking stylus and the Y's were defined to be the proportion of successful access attempts using a non-inking stylus. Table 5 summarized the test and the results from the comparison of the inking stylus with the non-inking stylus for the operating conditions of lined paper and morning use. Table 5 indicates that there is no significant difference between the two systems using lined paper in the morning. The significance level was 0.01.

The results from the comparison of the CIC system using both an inking and a non-inking stylus on lined paper in the afternoon as well as the test itself are summarized in Table 6. The results demonstrated that there was not a

significant difference between the two systems using lined paper in the afternoon at a significance level of 0.01.

The next Sign Test performed compared the systems on unlined paper in the morning. The test and results are summarized in Table 7. These results suggest that there was, again, no difference among the systems due to operating conditions. The significance level was 0.01.

The last Sign Test for this set of four compared the CIC system with an inking stylus and a non-inking stylus using unlined paper in the afternoon. The test and its results are again summarized in Table 8. Analyzing the results show that there was no significant difference in the systems because of the operating conditions. In other words using unlined paper in the afternoon did not significantly alter the performance of one system over the other. The significance level was 0.01.

To summarize the results from this set of Sign Tests, there was no significant difference in the performance of the CIC system due to the use of an inking or a non-inking stylus for the type of paper and the time of use.

3. The CIC System vs. The Sign/On System for Impostor Testing

The next set of four Sign Tests was used to compare the CIC system and the Sign/On system under the different operating conditions for the impostor testing portion of the

experiment. The definition of a successful access attempt changed for the impostor testing. A successful access attempt was one in which the system successfully identified an impostor and did not grant access. For three of the operating conditions none of the impostors were granted access and, therefore, the tests and their corresponding results were not presented. This was the case for (1) lined paper and morning use, (2) lined paper and afternoon use, and (3) unlined paper and afternoon use. For the conditions of unlined paper and morning use, two impostors were granted access on the Sign/On system and one impostor was granted access on the CIC system. Table 9 summarized the results and the test for the conditions of unlined paper and morning use. There was not a significant difference between the two systems under these conditions. The significance level was 0.01.

As before, this set of Sign Tests did not indicate a significant difference in system performance between the CIC and the Sign/On systems for impostor testing due to lined or unlined paper or due to morning or afternoon use.

4. **The CIC System with Inking Stylus vs. The Sign/On System with Non-Inking Stylus For Impostor Testing**

The final set of four Sign Tests comparing the CIC system with an inking and a non-inking stylus for impostors under the different operating conditions was then performed. A total of three impostors were granted access on the CIC

system with a non-inking stylus. Two of these impostors were granted access in the afternoon on lined paper. The third impostor was granted access in the afternoon on unlined paper. The impostor who was granted access on the CIC system with an inking stylus in the previous phase did not participate in this phase of the experiment and, therefore, for this series of Sign Tests there were no impostors granted access on the CIC system with an inking stylus. Table 10 summarized the test and the results for the lined paper and afternoon use of the impostor testing. The results indicated that there was no significant difference between the system with an inking stylus and a non-inking stylus. The significance level was 0.01.

The Sign Test and its results for the impostor testing during the afternoon using unlined paper were summarized in Table 11. The results indicated that the CIC system using an inking stylus did not perform any better than the same system with a non-inking stylus. Again, the significance level of 0.01 was used.

In summary, this set of four Sign Tests for impostor testing did not demonstrate a significant difference in performance between the CIC system using an inking or a non-inking stylus for the paper conditions and the time conditions.

5. Sign Tests for Combined Operating Conditions

By combining all the operating conditions into a single measure for each system, an overall measure for system performance will be obtained. In total four Sign Tests were completed in this series. The first test compared the CIC system with an inking stylus and the Sign/On system. Table 12 presented the test and the results. Once again the results indicated that there was no difference in the performance of either system. The significance level was 0.01.

The next Sign Test for the combined operating conditions compared the CIC system using an inking stylus and a non-inking stylus. The test and results are summarized in Table 13. At a significance level of 0.01, there was no difference in the performance of the CIC system due to the condition of the stylus.

Combining the operating conditions for the impostor testing was next. Comparing the CIC system and the Sign/On system for this Sign Test produced the results in Table 14. These results indicated that there was no significant difference between the two systems for impostor testing. The significance level was 0.01.

The last Sign Test for the combined operating conditions compared the CIC system using an inking and a non-inking stylus for the impostor testing. Table 15 summarized the results from that test as well as the test itself. The total number of impostors granted access was two. The results

indicated that the CIC system with an inking stylus did not perform significantly better than the same system with a non-inking stylus. The significance level was 0.01.

C. CONFIDENCE INTERVALS

In addition to the hypothesis testing done with the Sign Tests, confidence intervals were computed to estimate the proportion of successful access attempts for the CIC system with an inking stylus, the Sign/On system, and the CIC system with a non-inking stylus. The confidence intervals were computed for both the subjects' access attempts and the impostors' access attempts. Because of the large values for the proportion of successful access attempts, the Poisson approximation to the Binomial was used to compute the three confidence intervals for impostor testing (Duncan, 1986, pp. 100-103). Specifically, the Cumulative Probability Curves for the Poisson Distribution were used (Duncan, 1986, pp. 94, 573-574). The confidence intervals for the proportion of successful access attempts during non-impostor testing, however, were computed using the Normal approximation to the Binomial because the actual number of authorized subjects denied access was greater than 30 (Duncan, 1986, p. 574). The six confidence intervals were as follows:

1. CIC system with inking stylus
   p = proportion of successful access attempts = 0.9862
   CONFIDENCE INTERVAL: $Pr(0.981 < p < 0.991) = 0.95\%$

2. Sign/On system
   p = 0.9764
   CONFIDENCE INTERVAL: Pr(0.970 < p < 0.983) = 0.95%

3. CIC system with non-inking stylus
   p = 0.9824
   CONFIDENCE INTERVAL: Pr(0.976 < p < 0.989) = 0.95%

4. CIC system with inking stylus for impostor testing
   p = 0.9995
   CONFIDENCE INTERVAL: Pr(0.998 < p < 1.000) = 0.95%

5. Sign/On system for impostor testing
   p = 0.9991
   CONFIDENCE INTERVAL: Pr(0.997 < p < 1.000) = 0.95%

6. CIC system with non-inking stylus for impostor testing
   p = 0.9974
   CONFIDENCE INTERVAL: Pr(0.992 < p < 0.999) = 0.95%

D. DEPARTMENT OF DEFENSE GUIDELINES

The DOD has directed the United States Air Force as the lead agency to study equipment used to automate physical security access control (Bright, 1987, p. 33). Under that tasking, the Air Force has provided guidelines for the use of automated access control devices. These guidelines define a goal of 0.0% for both Type I and Type II errors for an access control system. However, the Air Force set the minimum requirement for access control systems at 3.0% Type I errors and 1.0% Type II errors (Bright, 1987, p. 33). Both the CIC system with an inking stylus and a non-inking stylus and the Sign/On system exceed those minimums and provide effective access control.

E. OTHER CONSIDERATIONS

There are several other factors besides performance which impact an access control device. Some of these are the level of security required, the cost to operate the system, the administrative burden, and the convenience to the user.

The level of security required is probably the most important factor to consider after performance. Highly classified material will obviously demand a more stringent access control system than personal privacy information. The ultimate responsibility for determining the level of access control required is set by the individual commanding officer (OPNAVINST 5510.1H, 1988, p.2-5). He must be assured by performance measures that the access control system is adequate for the level of information sensitivity.

The cost to operate a signature verification system is very low. After an initial purchase price, the system's operating costs are essentially covered by paper and, in the case of the CIC system, ink. The approximate purchase price of the CIC system is $1500 while for the Sign/On system the purchase price is $1900. These prices, however, are approximate due to the fact that each individual system would be tailored to fit the security needs of the user.

The administrative burden associated with access control can be considerable. With an access control system relying on devices such as passwords or keys the record keeping can be burdensome, especially at very large commands. Signature

verification systems on the other hand are not an administrative burden. Both the CIC system and the Sign/On system provide quick and easy administrative maintenance. The bulk of administrative tasks would entail enrolling new users and deleting users who no longer need access. Each of these tasks can be accomplished in a matter of seconds depending on the operating capacity of the computer the signature verification system is using. The only other administrative concern is the amount of storage needed for authorized users. This concern is again a function of the operating capacity of the computer the system is using.

Finally, user convenience is an important factor for access control. Signature verification systems are very easy to learn and use especially with and effective enrollment procedure.

IV. CONCLUSIONS AND RECOMMENDATIONS

The results from this experiment indicated that both the CIC On-line Dynamic Signature Verification system using an inking stylus and the Sign/On system produced by Capital Security Systems Incorporated were effective biometric access control devices. The CIC system with an inking stylus had a Type I error rate of 1.38% and a Type II error rate of 0.05%. The Sign/On system had a Type I error rate of 2.36% and a Type II error rate of 0.09%. In other words authorized users were denied access 1.38% of the time on the CIC system and 2.36% of the time on the Sign/On system and impostors were granted access 0.05% of the time for the CIC system and 0.09% of the time for the Sign/On system. The small difference in the percentages was not statistically significant. Both systems exceed the minimum requirements for access control devices set by the United States Air Force and as such provide adequate security measures for sensitive information. Additionally, the experimental results also indicated that the operating conditions of lined or unlined paper and morning or afternoon use did not significantly affect system performance. These results seem to support the claim that the signature is similar to a conditioned reflex.

Department of Defense security requirements have necessitated the need for stringent access control. Because

of the vulnerabilities of passwords, badges, and keys, signature verifications systems like the CIC system or the Sign/On system can provide more reliable and accurate access control systems and, thereby, reduce the current threat of unauthorized access. Although neither system is perfect, they did exceed the published minimum requirements for access control and either system is a feasible solution to an individual facility's access control problem. The choice remains with the facility's commander.

There are some other areas of concern to be investigated prior to widespread implementation of signature verification systems used for access control. The first of these is the environment in which the system operates. Signature verification systems may not be appropriate for deployable military units. A second concern is the traffic flow to the controlled area of information. The size of the facility may have a decided effect on an access control system. A third concern is a cost benefit analysis. Finally, verification of these experimental results in an operational environment would demonstrate the effectiveness of signature verification systems for access control.

APPENDIX

Table 2. SIGN TEST FOR THE CIC SYSTEM vs. THE SIGN/ON SYSTEM ON LINED PAPER IN THE AFTERNOON

SUBJECT*	CIC	SIGN/ON	DIFFERENCE
1	1.000	0.950	+
2	0.875	0.958	-
3	0.900	0.750	+
4	0.950	0.800	+
5	0.958	1.000	-
6	0.917	0.958	-

The hypotheses are:

Ho: The CIC system and the Sign/On system have the same proportion of successful access attempts on lined paper in the afternoon

Ha: The CIC system and the Sign/On system do not have the same proportion of successful access attempts on lined paper in the afternoon

$\alpha = 0.01$

The observed number of plus signs is 3 out of a possible 6. From any Binomial Distribution Table, the corresponding probability level is 0.6562.

Because the probability level is greater than α, one **CANNOT REJECT THAT THE PROPORTION OF SUCCESSFUL ACCESS ATTEMPTS FOR BOTH SYSTEMS ARE THE SAME ON LINED PAPER IN THE AFTERNOON AT A SIGNIFICANCE LEVEL OF 0.01.**

* only subjects with differences not equal to 0 were considered

Table 3. SIGN TEST FOR THE CIC SYSTEM vs. THE SIGN/ON SYSTEM ON UNLINED PAPER IN THE MORNING

SUBJECT*	CIC	SIGN/ON	DIFFERENCE
1	1.000	0.958	+
2	1.000	0.833	+
3	1.000	0.917	+
4	1.000	0.958	+
5	0.958	0.917	+
6	0.917	1.000	-
7	0.917	0.875	+
8	1.000	0.917	+
9	0.958	1.000	-
10	1.000	0.958	+

The hypotheses are:

Ho: The CIC system and the Sign/On system have the same proportion of successful access attempts on unlined paper in the morning

Ha: The CIC system and the Sign/On system do not have the same proportion of successful access attempts on unlined paper in the morning

$\alpha = 0.01$

The observed number of minus signs is 2 out of a possible 10. From any Binomial Distribution Table, the corresponding probability level is 0.0547.

Because the probability level is greater than α, one **CANNOT REJECT THAT THE PROPORTION OF SUCCESSFUL ACCESS ATTEMPTS FOR BOTH SYSTEMS ARE NOT THE SAME ON UNLINED PAPER IN THE MORNING AT A SIGNIFICANCE LEVEL OF 0.01.**

* only subjects with differences not equal to 0 were considered

Table 4. SIGN TEST FOR THE CIC SYSTEM vs. THE SIGN/ON SYSTEM ON UNLINED PAPER IN THE AFTERNOON

SUBJECT*	CIC	SIGN/ON	DIFFERENCE
1	1.000	0.958	+
2	0.958	1.000	-
3	1.000	0.875	+
4	0.950	1.000	-
5	0.958	1.000	-
6	1.000	0.958	+
7	0.958	0.875	+
8	1.000	0.958	+
9	0.875	1.000	-
10	0.958	1.000	-
11	0.958	1.000	-

The hypotheses are:

Ho: The CIC system and the Sign/On system have the same proportion of successful access attempts on unlined paper in the afternoon

Ha: The CIC system and the Sign/On system do not have the same proportion of successful access attempts on unlined paper in the afternoon

$\alpha = 0.01$

The observed number of plus signs is 5 out of a possible 11. From any Binomial Distribution Table, the corresponding probability level is 0.5000.

Because the probability level is greater than α, one **CANNOT REJECT THAT THE PROPORTION OF SUCCESSFUL ACCESS ATTEMPTS FOR BOTH SYSTEMS ARE THE SAME ON UNLINED PAPER IN THE AFTERNOON AT A SIGNIFICANCE LEVEL OF 0.01.**

* only subjects with differences not equal to 0 were considered

Table 5. SIGN TEST FOR THE CIC SYSTEM WITH INKING STYLUS vs. NON-INKING STYLUS ON LINED PAPER IN THE MORNING

SUBJECT*	INKING	NON-INKING	DIFFERENCE
1	1.000	0.958	+
2	0.917	0.830	+
3	0.958	1.000	-
4	0.875	1.000	-

The hypotheses are:

Ho: The CIC system using an inking stylus and a non-inking stylus have the same proportion of successful access attempts on lined paper in the morning

Ha: The CIC system using an inking stylus and a non-inking stylus do not have the same proportion of successful access attempts on lined paper in the morning

$\alpha = 0.01$

The observed number of plus signs is 2 out of a possible 4. From any Binomial Distribution Table, the corresponding probability level is 0.6875.

Because the probability level is greater than α, one **CANNOT REJECT THAT THE PROPORTION OF SUCCESSFUL ACCESS ATTEMPTS FOR THE SYSTEM IS THE SAME WHETHER OR NOT AN INKING STYLUS IS USED ON LINED PAPER IN THE MORNING AT A SIGNIFICANCE LEVEL OF 0.01.**

* only subjects with differences not equal to 0 were considered

Table 6. SIGN TEST FOR THE CIC SYSTEM WITH INKING STYLUS vs. NON-INKING STYLUS ON LINED PAPER IN THE AFTERNOON

SUBJECT*	INKING	NON-INKING	DIFFERENCE
1	0.950	1.000	-
2	0.958	0.833	+
3	0.917	1.000	-

The hypotheses are:

Ho: The CIC system using an inking stylus and a non-inking stylus have the same proportion of successful access attempts on lined paper in the afternoon

Ha: The CIC system using an inking stylus and a non-inking stylus do not have the same proportion of successful access attempts on lined paper in the afternoon

$\alpha = 0.01$

The observed number of plus signs is 1 out of a possible 3. From any Binomial Distribution Table, the corresponding probability level is 0.5000.

Because the probability level is greater than α, one **CANNOT REJECT THAT THE PROPORTION OF SUCCESSFUL ACCESS ATTEMPTS FOR THE SYSTEM IS THE SAME WHETHER OR NOT AN INKING STYLUS IS USED ON LINED PAPER IN THE AFTERNOON AT A SIGNIFICANCE LEVEL OF 0.01.**

* only subjects with differences not equal to 0 were considered

Table 7. SIGN TEST FOR THE CIC SYSTEM WITH INKING STYLUS vs. NON-INKING STYLUS ON UNLINED PAPER IN THE MORNING

SUBJECT*	INKING	NON-INKING	DIFFERENCE
1	1.000	0.850	+
2	1.000	0.950	+
3	0.900	0.792	+
4	0.958	1.000	-
5	0.958	1.000	-

The hypotheses are:

Ho: The CIC system using an inking stylus and a non-inking stylus have the same proportion of successful access attempts on unlined paper in the morning

Ha: The CIC system using an inking stylus and a non-inking stylus do not have the same proportion of successful access attempts on unlined paper in the morning

$\alpha = 0.01$

The observed number of minus signs is 2 out of a possible 5. From any Binomial Distribution Table, the corresponding probability level is 0.5000.

Because the probability level is greater than α, one **CANNOT REJECT THAT THE PROPORTION OF SUCCESSFUL ACCESS ATTEMPTS FOR THE SYSTEM IS THE SAME WHETHER OR NOT AN INKING STYLUS IS USED ON UNLINED PAPER IN THE MORNING AT A SIGNIFICANCE LEVEL OF 0.01.**

* only subjects with differences not equal to 0 were considered

Table 8. SIGN TEST FOR THE CIC SYSTEM WITH INKING STYLUS vs. NON-INKING STYLUS ON UNLINED PAPER IN THE AFTERNOON

SUBJECT*	INKING	NON-INKING	DIFFERENCE
1	0.958	1.000	-
2	0.958	0.625	+
3	0.958	1.000	-
4	0.958	1.000	-

The hypotheses are:

Ho: The CIC system using an inking stylus and a non-inking stylus have the same proportion of successful access attempts on unlined paper in the afternoon

Ha: The CIC system using an inking stylus and a non-inking stylus do not have the same proportion of successful access attempts on unlined paper in the afternoon

$\alpha = 0.01$

The observed number of plus signs is 1 out of a possible 4. From any Binomial Distribution Table, the corresponding probability level is 0.3125.

Because the probability level is greater than α, one **CANNOT REJECT THAT THE PROPORTION OF SUCCESSFUL ACCESS ATTEMPTS FOR THE SYSTEM IS THE SAME WHETHER OR NOT AN INKING STYLUS IS USED ON UNLINED PAPER IN THE AFTERNOON AT A SIGNIFICANCE LEVEL OF 0.01.**

* only subjects with differences not equal to 0 were considered

Table 9. SIGN TEST FOR IMPOSTOR TESTING FOR THE CIC SYSTEM vs. THE SIGN/ON SYSTEM ON UNLINED PAPER IN THE MORNING

SUBJECT*	CIC	SIGN/ON	DIFFERENCE
1	1.000	0.958	+
2	1.000	0.958	+
3	0.958	1.000	-

The hypotheses are:

Ho: The CIC system and the Sign/On system have the same proportion of successful access attempts for impostor testing on unlined paper in the morning

Ha: The CIC system and the Sign/On system do not have the same proportion of successful access attempts for impostor testing on unlined paper in the morning

$\alpha = 0.01$

The observed number of minus signs is 1 out of a possible 3. From any Binomial Distribution Table, the corresponding probability level is 0.5000.

Because the probability level is greater than α, one **CANNOT REJECT THAT THE PROPORTION OF SUCCESSFUL ACCESS ATTEMPTS FOR BOTH SYSTEMS FOR IMPOSTOR TESTING ARE THE SAME ON UNLINED PAPER IN THE MORNING AT A SIGNIFICANCE LEVEL OF 0.01.**

* only subjects will differences not equal to 0 were considered

Table 10. SIGN TEST FOR THE CIC SYSTEM WITH AN INKING STYLUS vs. NON-INKING STYLUS FOR IMPOSTOR TESTING ON LINED PAPER IN THE AFTERNOON

SUBJECT*	INKING	NON-INKING	DIFFERENCE
1	1.000	0.944	+
2	1.000	0.944	+

The hypotheses are:

Ho: The CIC system using an inking stylus and a non-inking stylus for impostor testing have the same proportion of successful access attempts on lined paper in the afternoon

Ha: The CIC system using an inking stylus and a non-inking stylus for impostor testing do not have the same proportion of successful access attempts on lined paper in the afternoon

$\alpha = 0.01$

The observed number of minus signs is 0 out of a possible 2. From any Binomial Distribution Table, the corresponding probability level is 0.2500.

Because the probability level is greater than α, one **CANNOT REJECT THAT THE PROPORTION OF SUCCESSFUL ACCESS ATTEMPTS FOR THE SYSTEM IS THE SAME WHETHER OR NOT AN INKING STYLUS IS USED FOR IMPOSTOR TESTING ON LINED PAPER IN THE AFTERNOON AT A SIGNIFICANCE LEVEL OF 0.01.**

* only subjects with differences not equal to 0 were considered

Table 11. SIGN TEST FOR THE CIC SYSTEM WITH INKING STYLUS vs. NON-INKING STYLUS FOR IMPOSTOR TESTING ON UNLINED PAPER IN THE AFTERNOON

SUBJECT*	INKING	NON-INKING	DIFFERENCE
1	1.000	0.944	+

The hypotheses are:

Ho: The CIC system using an inking stylus and a non-inking stylus have the same proportion of successful access attempts for impostor testing on unlined paper in the afternoon

Ha: The CIC system using an inking stylus and a non-inking stylus have the same proportion of successful access attempts for impostor testing on unlined paper in the afternoon

$\alpha = 0.01$

The observed number of minus signs is 0 out of a possible 1. From any Binomial Distribution Table, the corresponding probability level is 0.5000.

Because the probability level is greater than α, one **CANNOT REJECT THAT THE PROPORTION OF SUCCESSFUL ACCESS ATTEMPTS FOR THE SYSTEM IS THE SAME WHETHER OR NOT AN INKING STYLUS IS USED FOR IMPOSTOR TESTING ON UNLINED PAPER IN THE AFTERNOON AT A SIGNIFICANCE LEVEL OF 0.01.**

* only subjects with differences not equal to 0 were considered

Table 12. SIGN TEST FOR THE CIC SYSTEM vs. THE SIGN/ON SYSTEM

SUBJECT*	CIC	SIGN/ON	DIFFERENCE
1	1.000	0.966	+
2	1.000	0.990	+
3	0.934	0.948	-
4	1.000	0.969	+
5	0.955	0.920	+
6	1.000	0.960	+
7	0.989	0.920	+
8	0.969	1.000	-
9	1.000	0.990	+
10	0.938	0.927	+
11	0.979	0.938	+
12	0.969	0.990	-
13	0.969	1.000	-
14	0.948	0.969	-
15	1.000	0.938	+

The hypotheses are:

Ho: The CIC system and the Sign/On system have the same proportion of successful access attempts

Ha: The CIC system and the Sign/On system do not have the same proportion of successful access attempts

$\alpha = 0.01$

The observed number of minus signs is 5 out of a possible 15. From any Binomial Distribution Table, the corresponding probability level is 0.1509.

Because the probability level is greater than α, one **CANNOT REJECT THAT THE PROPORTION OF SUCCESSFUL ACCESS ATTEMPTS FOR BOTH SYSTEMS ARE THE SAME AT A SIGNIFICANCE LEVEL OF 0.01.**

* only subjects with differences not equal to 0 were considered

Table 13. SIGN TEST FOR THE CIC SYSTEM WITH INKING STYLUS vs. NON-INKING STYLUS

SUBJECT*	INKING	NON-INKING	DIFFERENCE
1	0.958	0.927	+
2	0.989	1.000	-
3	1.000	0.989	+
4	0.938	0.771	+
5	0.979	1.000	-
6	0.969	1.000	-
7	0.948	1.000	-

The hypotheses are:

Ho: The CIC system using an inking stylus and a non-inking stylus have the same proportion of successful access attempts

Ha: The CIC system using an inking stylus and a non-inking stylus do not have the same proportion of successful access attempts

$\alpha = 0.01$

The observed number of plus signs is 3 out of a possible 7. From any Binomial Distribution Table, the corresponding probability level is 0.5000.

Because the probability level is greater than α, one **CANNOT REJECT THAT THE PROPORTION OF SUCCESSFUL ACCESS ATTEMPTS FOR THE SYSTEM IS THE SAME WHETHER OR NOT AN INKING STYLUS IS USED AT A SIGNIFICANCE LEVEL OF 0.01.**

* only subjects with differences not equal to 0 were considered

Table 14. SIGN TEST FOR THE CIC SYSTEM vs. THE SIGN/ON SYSTEM FOR IMPOSTOR TESTING

SUBJECT*	CIC	SIGN/ON	DIFFERENCE
1	1.000	0.989	+
2	1.000	0.989	+
3	0.989	1.000	-

The hypotheses are:

Ho: The CIC system and the Sign/On system have the same proportion of successful access attempts for impostor testing

Ha: The CIC system and the Sign/On system do not have the same proportion of successful access attempts for impostor testing

$\alpha = 0.01$

The observed number of minus signs is 1 out of a possible 3. From any Binomial Distribution Table, the corresponding probability level is 0.5000.

Because the probability level is greater than α, one **CANNOT REJECT THAT THE PROPORTION OF SUCCESSFUL ACCESS ATTEMPTS FOR BOTH SYSTEMS ARE THE SAME FOR IMPOSTOR TESTING AT A SIGNIFICANCE LEVEL OF 0.01.**

* only subjects with differences not equal to 0 were considered

Table 15. SIGN TEST FOR THE CIC SYSTEM WITH INKING STYLUS vs. NON-INKING STYLUS FOR IMPOSTOR TESTING

SUBJECT*	INKING	NON-INKING	DIFFERENCE
1	1.000	0.985	+
2	1.000	0.971	+

The hypotheses are:

Ho: The CIC system using an inking stylus and a non-inking stylus have the same proportion of successful access attempts for impostor testing

Ha: The CIC system using an inking stylus and a non-inking stylus do not have the same proportion of successful access attempts for impostor testing

$\alpha = 0.01$

The observed number of minus signs is 0 out of a possible 2. From any Binomial Distribution Table, the corresponding probability level is 0.2500.

Because the probability level is greater than α, one **CANNOT REJECT THAT THE PROPORTION OF SUCCESSFUL ACCESS ATTEMPTS FOR THE SYSTEM IS THE SAME WHETHER OR NOT AN INKING STYLUS IS USED FOR IMPOSTOR TESTING AT A SIGNIFICANCE LEVEL OF 0.01.**

* only subjects with difference not equal to 0 were considered

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